Treatment Wetlands—What Happened in Black Diamond

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Introduction

Several west coast communities are using or proposing to use treatment wetlands for municipal wastewater (sewage) treatment to improve effluent quality and to restore or enhance wildlife habitat.

This paper reviews the development history of treatment wetlands in Black Diamond, Washington, and five communities in Oregon and Northern California. The systems profiled here include the municipal wetland treatment systems in the region whose development history is notable, usually from a standpoint of regulatory compliance, and for whom a database exists to show how well the system works. The available information suggests that Black Diamond is unique in the use of an unimproved natural wetland; that Arcata is a success in part as a result of the application of beneficial use standards and watershed location; that well-designed and constructed first generation wetlands perform well with respect to the water quality parameters for which they are designed (biochemical oxygen demand and total suspended solids) and that the habitat created by municipal treatment wetlands is regionally significant, possibly replacing wetland functions and values of wetlands lost to development.

Black Diamond, Washington

Black Diamond is a town of approximately 1600 located at the base of the Cascade Range in western Washington, 30 miles southeast of Seattle. Until the early 1980s, the residents of Black Diamond were served by on-site and community septic systems (Thielen, 1978).

In 1979, Black Diamond adopted a wastewater facilities plan to construct an aerated lagoon and a "marsh-lagoon" to treat community wastewater. The marsh-lagoon, when constructed, would consist of two 3.5-acre, 4-foot deep lagoons sited within an existing 130-acre marsh. Nutrient removal, necessary for compliance with proposed permit conditions, would be achieved in part through an annual harvest of marsh-lagoon vegetation. Marsh-lagoon effluent would be discharged to the surrounding wetland, which is traversed by Rock Creek upstream of Lake Sawyer (Kramer, Chin and Mayo, 1979 and 1980).

Construction in the existing wetland required a US Army Corps of Engineers permit. During the permitting process, United States Environmental Protection Agency (EPA) wetlands staff, other resource agency staff, and environmental organizations objected to the siting of a treatment facility in an existing wetland. Agency staff recommended that the city limit wetland improvements to installation of a weir at a downstream location to increase detention time and treatment, or that the city use an alternative wetland, one that was being invaded by trees and which was, as a result, losing marsh characteristics (Kramer, Chin and Mayo, 1980).

The town was apparently surprised by these objections, believing that EPA and the Washington State Department of Ecology (Ecology) had approved the use of the wetland with the approval of the facilities plan.

In response to these comments, Black Diamond prepared a facilities plan addendum that evaluated the proposed marsh-lagoon and, alternatively, use of the 130-acre marsh in its natural state. The study concluded that both systems could meet nutrient effluent limits but that a decrease in phosphorus reductions could be expected during the 20-year life of the project. The study recommended use of the natural wetland. Advantages of using the natural wetland included lower construction-related environmental impacts and a savings of several hundred thousand dollars in construction costs. The town also avoided the Corps permitting process under this alternative (Kramer, Chin and Mayo, 1980; Stephens, 1986).

The treatment system, an aerated lagoon with natural marsh treatment, qualified for 100% funding from EPA under Innovative and Alternative funding criteria and began operating in 1981. Shortly thereafter, algal blooms were reported in Lake Sawyer (Peterson, 1990).

In 1985, after several years of treatment plant operation and reports of increased algae in Lake Sawyer, a consultant was hired to evaluate the performance of the Black Diamond facility. The consultant concluded that the system was not meeting mass removal performance requirements for biochemical oxygen demand (BOD), total suspended solids (TSS), and phosphorus. Samples taken in May, 1985, showed approximately 70% BOD removal, whereas the town's discharge permit specified 85% removal. Inorganic nitrogen was reduced by 85%, compared to the seasonal removal requirement of 70% . Total nitrogen was reduced by 55%. Phosphorus concentrations in Rock Creek were reported to be ten times that of pre-discharge concentrations. The study noted that surface and/or groundwater flow into the marsh provided 50-fold dilution of the influent and was partially responsible for decreases in pollutant concentrations (R.W. Beck and Associates, 1985).

EPA was approached to fund system improvements when it became apparent that Black Diamond was not meeting permit limits. EPA staff were initially concerned with the amount of data available to support a finding of failure—a finding necessary for EPA to fund improvements under existing effluent limits. EPA could also fund improvements if the parties agreed that more stringent limits were needed based upon receiving water sensitivity. However, EPA suggested that more stringent limits could be prescribed only if supported by an evaluation of all pollution sources to Lake Sawyer (Catey, 1986; Joy, 1987; Saikewicz, 1988; Williams, 1989).

The location and possible dearth of monitoring stations may have created difficulty in evaluating the performance of the Black Diamond wetland. Shortly after the system went on-line, the effluent sampling point was established in Rock Creek downstream of the wetland. Water quality at this station would be affected by upstream watershed influences. The choice of this location as a sampling point may reflect the integrated nature of Rock Creek and the wetland—that is, it may have been difficult or impossible to find a discrete location defining the wetland discharge into the creek. Additionally, several unmonitored creeks and springs fed the wetland.

In 1988, despite EPA's previous recommendation for a watershed-based analysis, Ecology proposed more restrictive effluent limits for Black Diamond. The following year, a consultant to Black Diamond summarized alternatives available to meet the new limits and recommended abandonment of the lagoon/marsh system in favor of conveyance to a regional treatment facility (Brown and Caldwell, 1989).

In 1991, Ecology published the results of a year long study of Lake Sawyer. The report described the condition of Lake Sawyer as mesotrophic with an 18% expectation of attaining eutrophic conditions. The report concluded that the Black Diamond wastewater treatment facility accounted for 40% of the lake's external phosphorous load and that removal of the discharge from the creek would decrease the likelihood of eventual eutrophication. The report noted that development in the Rock Creek watershed had also contributed to deteriorating water quality in Rock Creek and recommended management practices for the control of phosphorus from future development (Carroll and Pelletier, 1991).

The diagnostic study also reported that the lagoon and wetland treatment system removed roughly 77% of the phosphorus and 73% of the nitrogen from Black Diamond's waste stream. The report noted that these reductions surpassed original design expectations.

Even before publication of the 1991 Ecology study, EPA was apparently satisfied with the accumulation of data and experience at Black Diamond. The agency adopted a finding of failure and funded a connection to the regional wastewater collection system. Black Diamond's wastewater is now treated at the regional facility in Renton.

Wetland influent and effluent data from Black Diamond for 1990 and 1992, two of the last three years of operation, are presented in the Discussion section.

Cannon Beach, Oregon

Cannon Beach is located 100 miles west of Portland, Oregon. Since 1984, this coastal community of 1300 has treated its wastewater using aerated and facultative lagoons and a 15-acre modified natural free-water-surface treatment wetland. Planning for the treatment system occurred over a period of years and generated some local controversy.

In the 1970s, summer flows to the existing wastewater treatment plant exceeded permit effluent limits and the design capacity of the plant. In response to these conditions, Cannon Beach prepared an updated facilities plan and supplement in 1976 and 1977. However, the Cannon Beach Sewer Advisory Board saw "no justification in backing a conventional collection and treatment approach...," and recommended that the City Council explore alternative technologies instead (Cannon Beach Sewer Advisory Board, 1980).

The town, with considerable citizen involvement, eventually proposed a system that included a treatment marsh and previously recommended lagoon upgrades to meet summer seasonal limits on BOD and TSS (10/10 mg/L). Like Black Diamond, Cannon Beach recommended use of and improvements to a local natural wetland. Berms would be placed around the wetland to improve detention and redwood baffles would be placed in the wetland to prevent flow short-circuiting (Kramer, Chin, & Mayo, 1978).

Both the Oregon Department of Fish and Wildlife and the United States Fish and Wildlife Service objected to the use of a natural wetland for wastewater treatment.

In response to agency concerns, the city contracted for a biological evaluation of the wetland. The evaluation noted that the proposed 15-acre wetland treatment area included five different plant communities, four of which were forested, and that the wetland was used by a number of wildlife species, including Roosevelt elk, beaver, mallards, canvasbacks, great blue herons, kingfishers, and pileated woodpeckers. The report noted, however, that the site was part of a larger, 150-acre wetland, suggesting that previous fears of losing a unique wetland were possibly unfounded, and that the site was originally much drier. The site had developed wetland characteristics as a result of logging and changes in site drainage accompanying development (Kramer, Chin, & Mayo, 1981).

As a result of the biological evaluation, the city proposed a modified design that minimized fencing to allow continued wildlife access and used planted earthen baffles instead of redwood baffles. The biological information and proposed modifications apparently satisfied resource agency concerns. The modified plan was adopted by the Cannon Beach City Council, approved by the Oregon Department of Environmental Quality, and funded by EPA as an Innovative and Alternative project. The treatment system began operating in 1984. The wetland is used only for summer flows. Discharge is to Ecola Creek, about one-half mile above the mouth of the creek at the Pacific Ocean (US EPA, 1993; Oregon State Department of Environmental Quality, 1993). Wetland data are presented in the Discussion section.

Unified Sewerage Agency (Hillsboro, Oregon)

The Unified Sewerage Agency (USA) serves an urbanizing area in Washington County in the northern Willamette River valley in the state of Oregon. USA operates four wastewater treatment plants with a combined flow of approximately forty million gallons per day (40 mgd). These plants discharge to the Tualitin River during winter months and to reclamation facilities, including the 15-acre Jackson Bottoms Experimental Wetland (JBEW), between April and October. Development of reclamation facilities was spurred in part by the settlement of two lawsuits by the Portland-based Northwest Environmental Defense Center. One suit, related to promulgation of TMDLs for phosphorus for 11 Oregon streams, including the Tualitin, was settled in 1988; a second, related to alleged violations of permit conditions by USA, was settled in 1989. The JBEW, in use since 1989, treats secondary effluent discharged from the two mgd Hillsboro wastewater treatment plant (Unified Sewerage Agency, 1990).

The JBEW was developed to investigate the use of a treatment wetland to remove nutrients from wastewater and to investigate the use of wastewater to enhance biodiversity in a wetland dominated by reed canary grass (*Phalaris arundinacea*). The treatment wetland is a constructed free-water-surface wetland developed out of an existing wetland. The wetland is comprised of 17 cells underlain by three soil types. Shallow areas (1 ft. depth) are planted with *Typha* and transition to deeper areas (3 ft. depth) planted with sago pondweed (*Potamogeton pectinaturs*) (Geiger et al., 1993; Scientific Resources and Luzier Hydrosciences, 1990). The wetland is located within the 434-acre Jackson Bottoms Wetland Preserve, owned by USA and the City of Hillsboro and managed in accordance with a Natural Resource Management Plan and permits issued by the Oregon Division of State Lands and the US Army Corps of Engineers. In 1992, approximately 474 million gallons of effluent were distributed to 350 acres of land within the Preserve.

Treatment at JBEW is complicated by site hydrology and topography, and possibly by initial construction practices. The wetland was originally planned as a single, sinuous, flow-through system. However, the pre-construction survey suggested that flat site conditions would preclude such a design and wetland cells were built instead. Subsequently, after the third year of operation, USA staff reported that some flow thought to discharge to groundwater discharged instead through berms into adjacent drainage ditches. Consultants estimated that 20% of inflows discharged to groundwater through wetland soils, and 30% of inflows discharge through side berms to the local drainage system, and that short-circuiting could be the result of poor initial construction practices (Scientific Resources et. al., 1995).

Reed canary grass continued to thrive and even increased in extent over the initial 3-year monitoring period. Previously, researchers at the site had not observed the grass growing in conditions of continuous flooding. Although reed canary grass is not a preferred species, the wetland evidently provides nesting habitat for a number of avian species (Willis, personal communication). Wetland data are presented in the Discussion section.

Mt. View Sanitary District (Martinez, California)

The Mt. View Sanitary District serves a community of 16,000 living in and around the City of Martinez, California, in the San Francisco Bay Area. The District operates a 1.3 mgd advanced secondary treatment plant that discharges to a 21-acre constructed, free-water-surface wetland. Treatment wetlands and recent plant upgrades to protect wetland habitat were developed as a result of an evolving regional regulatory policy.

In 1969, when the District upgraded to secondary treatment, it decided to continue its discharge to Peyton Slough rather than construct a force main to, and a new outfall in, the Carquinez Straights within the Sacramento River/San Francisco Bay Estuary. Subsequently, in 1971, the San Francisco Bay Regional Water Quality Control Board (RWQCB) adopted a basin plan which prohibited discharges to receiving waters that provided less than 10:1 dilution, including Peyton Slough. The plan allowed for exemptions when the discharger could show that the discharge resulted in a "net environmental benefit."

In 1974, the District constructed a nine-acre freshwater marsh, redirected part of its discharge to that marsh, and started a three-year pilot study to demonstrate compliance with the new regional policy.

At about the time the District was completing its pilot study, in 1977, the RWQCB adopted a policy that stipulated that marshes created under the net environmental benefit exemption were to be protected as receiving waters. As a result, Mt. View is required to meet effluent limits for its discharge to the constructed wetland, rather than for the discharge from the wetland to Peyton slough.

The Mt. View Sanitary District has pursued two courses of action over the past twenty years to comply with regulatory agency policy regarding net environmental benefit. First, the District expanded its created freshwater marsh to 21 acres in 1977 and later purchased 65 acres of adjacent brackish marsh immediately downstream. Second, between 1992 and 1995, the District completed treatment plant upgrades that reduced the discharge of ammonia to the marsh and replaced chlorine-based disinfection with filtration and ultra-violet light (Wilson, personal communication).

Even before treatment plant upgrades, the created wetland provided significant regional habitat within the industrializing I-680 highway corridor. By 1986, district biologists have documented over 100 species of birds using the wetland area. Observations have been made on 58 species of wading birds and waterfowl, seven species of raptors, and ten species of gulls and terns. An assemblage of invertebrates, fish, amphibians, and reptiles also uses the wetland, including the western pond turtle (*Clemmys marmorata*) (Bogaert and Fish, 1986). The western pond turtle is an endangered species in Washington State and a federal species of concern.

Wetland data are presented in the Discussion section.

Arcata, California

The City of Arcata is a community of 19,000 located on California's northwest coast, 100 miles south of the Oregon border. The city is served by a 2.3 mgd wastewater treatment facility comprised of primary clarifiers, oxidation ponds, 7.5 acres of treatment wetlands, and 31 acres of treatment/enhancement wetlands. Discharge is to Humboldt Bay. The City developed the treatment system in the late 1970s and early-to-mid 1980s amidst considerable local controversy and as a result of changes in state regulatory policy.

In 1974, the State Water Resources Control Board adopted the "Bays and Estuaries Policy" prohibiting discharges into California's shallow bays and estuaries, including Humboldt Bay, unless the discharger could show that the discharge enhanced the "beneficial uses" of the receiving water. After some research, the city concluded that a marsh treatment system would enhance the beneficial uses of Humboldt Bay. Those uses include, among others, recreation (water-contact and non-water contact), wildlife habitat, preservation of rare and endangered species, marine habitat, fish migration, fish spawning, and shellfish harvesting.

In 1979, the city applied for and received funds from the California State Coastal Conservancy to acquire and develop former marsh lands adjacent to the wastewater treatment plant for wetland habitat restoration, public access, and the beneficial use of wastewater for marsh enhancement. The city completed restoration work on these enhancement marshes in July, 1981 (Mangelsdorf, 1993).[1]

Simultaneously, the City entered into negotiations with state regulatory officials. The City requested that the state approve funding for a pilot project to investigate the use of treatment wetlands to enhance the beneficial uses, including wildlife habitat, of Humboldt Bay. Initially, state regulatory agencies resisted City overtures. As a result, local political leaders introduced legislation at the state level to exempt Arcata from the Bays and Estuaries Policy and allow it to continue discharging directly to Humboldt Bay. According to Mangelsdorf, the legislation "...was heard before the Assembly Committee on Water, Parks and Wildlife and when the State (Water Resources Control Board) Chairman was unable to define the term 'enhancement' for the Assembly Committee, the Committee immediately passed the bill."

Shortly thereafter, the State Water Board reversed a previous position and adopted a resolution authorizing the City to proceed with pilot studies.

The state approved Arcata's wetlands treatment plan after a three-year pilot project. Arcata completed treatment plant upgrades and redirected discharges from the treatment plant to its enhancement wetlands in 1986. Additional treatment marshes were added in 1989. The Arcata City Council has designated the enhancement marshes and surrounding open space the Arcata Marsh and Wildlife Sanctuary (AMWS).

The enhancement marshes are unique from a regulatory standpoint in that the marshes are apparently both regulated waters of the state and an element of the City's wastewater treatment facility. As described in the City's NPDES permit, the enhancement wetlands are regulated as "...waters of the state and the United States...":

> The treatment plant is designed to discharge disinfected wastewater treated to secondary standards to waters of the State and the United States at two locations. Outfall 001 discharges directly to Humboldt Bay. Outfall 002 discharges to the Arcata Marsh (and) Wildlife Sanctuary which consists of 30 acres of freshwater wetland.

The NPDES permit states elsewhere that,

> Continued discharge to Humboldt Bay and compliance with the Bays and Estuaries Policy was achieved by the inclusion of the Arcata Marsh (and) Wildlife Sanctuary as part of the treatment and discharge facility.

As with the Mt. View Sanitary District, effluent limits are set for discharges to the AMWS, but these limits (30/30 for BOD/TSS) are not reflective of effluent limits that could be required for a discharge into a wetland.

Arcata's discharge is based upon a continued showing by the City that the discharge is enhancing the beneficial uses of Humboldt Bay. The City has sponsored research to demonstrate compliance with these standards. Gearheart and Higley (1993) review data on wildlife and public use of the 150-acre marsh and wildlife sanctuary. According to these researchers, over 170 species of birds have been observed in the AMWS, with 1.4 million waterbird use-days recorded annually between 1984 and 1986. Nesting species included mallards, cinnamon teal, northern shoveler, pied-billed grebe, killdeer, and black-necked stilt. The area includes five miles of trails and has become "...a major form of low-cost recreation for bird watchers, nature lovers, fishermen, walkers, joggers, boaters, picnickers, meditators, and tourists." The authors report that, "In a 1987 user survey, the most common reasons given for going to AMWS was its value as a human sanctuary and as a place to enjoy the natural setting and ecology of a marsh." The Redwood Audubon Society conducts weekly nature walks at the AMWS and approximately 900 people a year participate.

Wetland data are presented in the following section.

Discussion

Table 1 presents design information on the treatment wetlands profiled in this paper. Table 2 presents influent and effluent data for the wetlands. Acreage data for Black Diamond in Table 1 is qualified as there is uncertainty as to the amount of acreage contributing to treatment given the presence of Rock Creek and the resulting potential for short-circuiting.

The Black Diamond treatment wetland is the only natural treatment wetland of the five profiled (Table 1). In contrast, treatment wetlands at Cannon Beach and USA were developed by modifying existing wetlands. These modifications are designed to improve detention time and limit short-circuiting and thereby produce an improved effluent quality. Arcata and the Mt. View Sanitary District (Mt. View SD) use constructed treatment wetlands, again to create a controlled environment for treatment.

The data from Arcata and Cannon Beach confirm early design principles that, in relatively small areas, well designed and constructed (or modified) wetlands reduce effluent concentrations of BOD and TSS to levels below 20 mg/L. The relatively high BOD concentration in USA effluent is notable given the concentrations reported at the other facilities.

Table 1. Treatment Wetland Design Washington, Oregon, and Northern California Treatment Wetlands.

System	Year	mgd	Acres/mgd	Pre-treatment	Type
Mt. View SD, CA	1974	1.3	16	Secondary	Constructed
MVSD Upgrade[1]	1995			Adv. Sec.	
Bl. Dmd., WA	1981	0.15	870[2]	Primary	Natural
Can. Beach, OR	1984	0.5	30	Secondary	Mod. Nat.[3]
Arcata, CA	1986	2.3	17	Secondary	Constructed
USA, OR	1989	0.7	21	Secondary	Mod. Nat.[3]

1. Nitrification.
2. Contributing treatment area is unclear.
3. Modified Natural Wetland.

Table 2. Treatment Wetland Influent and Effluent Data (Influent to Wetland; Effluent from Wetland).

	Flow (*mgd*)			BOD (*mg/L*)			TSS (*mg/L*)			NH_3 (*mg/L*)			$NO_{3/2}$ (*mg/L*)			Total P (*mg/L*)		
	In.	Ef.	Loss	In.	Ef.	Rem.	In.	Ef.	Rem.	In.	Ef.	Rem.	In.	Ef.	Rem.	In.	Ef.	Rem.
Bl. Diamond-1990	0.17	NA		20	NA		25	NA			.65			.64			.37	
Bl. Diamond-1992	0.13	NA		15	NA		54	NA			.78			1.2			1.3	
Cannon Beach-1996[1]	0.5	0.24	45%	47	5	86%	51	2	96%	12	9.2	21%	2.5	4.7	-83%	2.1	1.9	10%
USA-1990[2]	0.5	0.13	73%	40	51	-28%	9	12	-28%	3.2	0.1	97%	6.9	2.2	68%	7.6	4.0	47%
USA-1992	1.0	0.36	66%	41	71	-73%	5	16	-232%	15	6.4	57%	18	8.2	54%	3.3	3.1	117%
Mt. View SD-1995	2.0	NA		12	NA		9	NA		1.1	1.0	10%	19	13	30%		NA	
Mt. View SD-1996	2.0	NA		6	NA		8	NA		1.0	0.3	30%	18	14	27%		NA	
Arcata – 1994[3]	2.1	1.5	30%	NA	10		NA	15			NA			NA			NA	
Arcata – 1995	2.7	1.6	40%	NA	14		NA	27			NA			NA			NA	

Data are compiled from NPDES reports, unless otherwise noted. (NA: Not Available).

Some date values are rounded; percentages are based upon original (not rounded) data.

The 1992 data is generally representative of the years 1989-1992.

Between 1990 and 1992, the Hillsboro plant stopped nitrification of wastewater, the result of a 25% increase in wastewater flows, and a service-area-wide ban on phosphorus went into effect. Data are mean values for 17 cells. Data compiled from Scientific Resources et al. (1995) for a three year pilot study.

The 1994 data is generally representative of the year 1992-1994.

On a mass loading basis, pollutant reductions are substantial at most locations, the result of subsurface discharges. None of these wetlands is lined.

These small wetlands are only partially successful in reducing nutrient concentrations. Effluent concentrations of nitrogen are indicative of partial nitrification/denitrification. Nitrogen data from Mt. View SD demonstrates the potential for denitrification. There, nitrification occurs as part of pre-treatment and reduced ammonia discharges probably contribute to increased habitat quality in the wetland.

In general, there has been an explosion of information related to wetlands design since these wetlands were planned and constructed. Recent publications include a comprehensive text (Kadlec and Knight, 1996), updated design manuals (Reed et al., 1995; Water Environment Foundation, 1990), conference proceedings (Hammer, 1988; Moshiri, 1993), and numerous trade journal articles and published papers. Reed and Brown review first generation design methodologies (Reed and Brown, 1992), report on a nation-wide inventory of treatment wetlands (Brown and Reed, 1994), and review experiences with sub-surface flow wetland (Reed and Brown, 1995). The wetlands reviewed here can be classified as first-generation wetlands.

Information developed since these first generation wetlands were built suggests that expanded acreage is needed for nutrient processing, compared to the acreage required for BOD and TSS removal (Hammer and Knight, 1994; Reed et al., 1995; Kadlec and Knight, 1996; Water Environment Foundation, 1990). Additionally, harvest of vegetation for nutrient management is no longer recommended as harvest removes attachment sites for the epiphytic community thought to control nutrient processing (Crites and Tchobanoglous, 1992; Brix, 1994), although some researchers have recommended this practice as recently as 1992 (Rogers et al., 1991; Rogers, 1992). A limited harvest is recommended to preserve open water habitat for *Gambusia* (mosquito fish), a species used in mosquito control programs (Tennessen, 1993; Nolte & Associates, 1996).

Design information also now suggests that phosphorus removal in most wetlands is limited—as it is in most treatment processes (Kadlec and Knight, 1996; Reed et al., 1995). Phosphorus is removed from water during plant growth, but it is returned in the form of plant litter. Phosphorus can be sequestered to some degree in the litter. Phosphorus is also removed via adsorption, complexation, and precipitation in soil during infiltration, but soil phosphorous storage capacity is finite. In areas where groundwater surfaces, phosphorus removal can be compromised by the limited contact between effluent and underlying soil, and potentially by the flushing of phosphorous stored seasonally in soil during periods of infiltration.

Both water quality and habitat quality were issues for the designers of the first generation wetlands profiled here. Water quality concerns increasingly result in the use of numeric water quality standards in NPDES permits. The water quality data in Table 1 is available because numeric standards are used in these permits.

In Arcata, where both numeric standards and narrative beneficial use standards are used, an emphasis on the latter may have contributed to project success. Specification of beneficial use standards resulted in a design for the enhancement wetlands that provided for both treatment and habitat. The Arcata enhancement wetlands use a mix of open water and emergent vegetation that provides, in addition to treatment, waterfowl habitat (Weller, 1978). The Mt. View SD wetlands also support a mix of open water and emergent vegetation, the result of district efforts to create habitat while improving effluent quality.

The lack of a data set for Black Diamond comparable to the other treatment wetlands profiled here is unfortunate. Not only was Black Diamond the only natural treatment wetland (of the five profiled), it was also the only treatment wetland of the five that was established high in a watershed. Without a suitable data set, it is difficult to say whether "failure" at Black Diamond was due in part or entirely to the treatment facility, or in part or entirely to watershed location, or some other factor. Watershed location deserves consideration.

For any treatment facility, an upstream location may reveal problems more readily than a downstream, estuarine location. An upstream facility discharges to a freshwater environment with relatively sensitive receptors. For Black Diamond, a major feature of the downstream environment is Lake Sawyer. Coincidentally, Black Diamond and Lake Sawyer are located in King County, Washington, the location of pioneering studies on the effects of nutrients on lake productivity (Edmondson, 1991). A year-round audience of lake residents was available to observe and report perceived changes in lake conditions during operation of the Black Diamond facility. As a result, the Black Diamond system operated in a somewhat unique environment, a result of location within the watershed and watershed location.

A treatment wetland in the estuary encounters a different set of environmental conditions. The estuarine environment, with diurnal variations in water cover and salinity, is hostile to many aquatic species, and some sensitive species, such as salmonids, are not resident. Aquatic productivity may not be limited by phosphorus. Daily tidal action may remove evidence of poor performance. Commercial users in the estuary may be less sensitive to or more forgiving of environmental change than the upstream counterpart, the home owner. An estuarine location may be better for attracting species of observable wildlife, thereby increasing the opportunity for perceived improvements of beneficial uses. Perhaps not coincidentally, the Arcata and Martinez (Mt. View SD) treatment wetlands are located in estuarine environments.

Nonetheless, experiences in Arcata and Martinez, California suggest that treatment wetlands can be used to enhance regional habitat. Data from these two locations support pilot habitat assessment data collected at other treatment wetlands (McAllister, 1992; McAllister, 1993a; McAllister, 1993b). Treatment effluent has been used in one national wildlife refuge to restore wetland habitat functions (Hardy, 1989; McAllister, 1992) and has enhanced regional habitat at a number of other locations (US EPA, 1993).

In addition to replicating wetland habitat functions, treatment wetlands could replicate the nutrient processing function of historic wetlands and thereby contribute to overall watershed health, although research in this area is lacking. The downstream export of detritus from wetlands is an important wetland function; in estuaries, such detritus supports the juvenile salmonid food chain (Naiman and Sibert, 1979; Sibert, 1979; Healy, 1979). Upstream wetlands perform a similar processing function and provide refuge habitat for juvenile salmonids (Peterson and Reid, 1981).

Treatment wetlands could be used to replicate the functions and values of wetlands that have been “lost” to development in Puget Sound watersheds. The loss of these wetlands has been noted by state and federal resource agency staff working regionally and within specific watersheds (Puget Sound Water Quality Authority, 1986; Washington State Department of Ecology, 1993; US Army Corps of Engineers et al., 1993). Recently, Ecology has published new water reuse standards that may influence the manner in which treatment wetlands are developed in Washington State (Washington State Department of Ecology, 1997). Whether or not the habitat qualities of treatment wetlands developed elsewhere will be re-created here under new Ecology standards remains to be seen.

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[1] Mangelsdorf credits Peter Bretnall, another graduate student at Humboldt State University in Arcata, for information she presents on the political history of the Arcata Project. The reference Mangelsdorf gives is: Bretnall, Peter B. *Wastewater Conflict on Humboldt Bay*. Humboldt Journal of Social Relations, 11 (Spring/Summer 1984): 128-151.